# Feedstock recycling of PLA – a biobased polymer goes circular

Antje Lieske and Daniel Maga
Fraunhofer Cluster Circular Plastics Economy CCPE

Circular Chemistry Conference,
March 8, 2022



Fraunhofer CCPE

# The Plastic Age – Some Numbers





Quelle: *Science Advances* 19 Jul 2017; Vol. 3, no. 7

# Fraunhofer CCPE - System Services for a Circular Plastics Economy

Business and Transformation

Circular Logistics and Sustainability

Circular Economy Assessment

1 Circular Assessment of molecules, materials, products …

Circular Readiness Level®

Circular Polymers

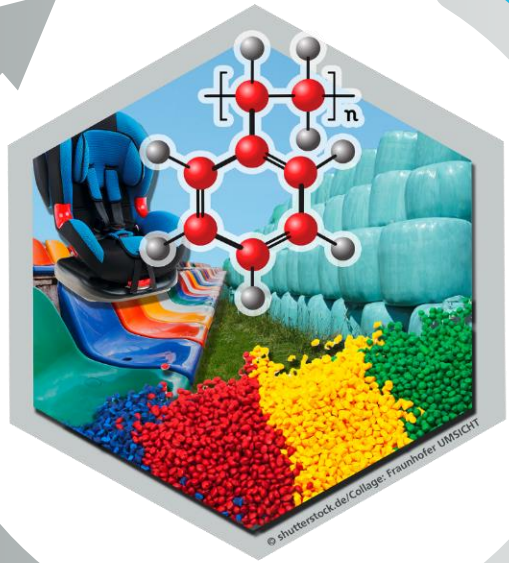
Circular Additives and Compounds

Licence management business models

Market acceptance

Circular molecules

Additive 2nd life




4 Products, IP, spin-offs, business models, and participation processes

2 Development of circular system solutions with industrial partners

Market studies

Product development

Secondary raw materials

Track and trace

Business and Transformation

Application and Demonstration

Product design studies

3 Circular prototypes for molecules, materials, product designs

Advanced Recycling

Circular Logistics and Sustainability



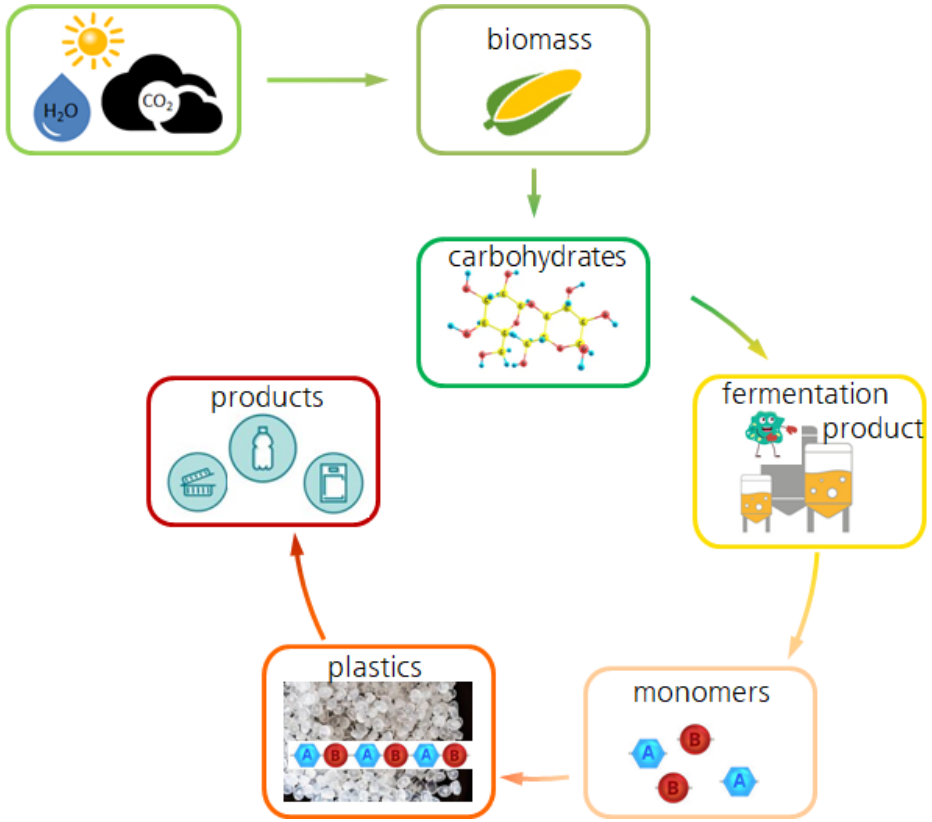

CIRCONOMY® Circular Solutions by Fraunhofer

Fraunhofer CCPE

# Biobased and Degradable – the Solution?

- energy used in production is lost
- good solution only if material flows cannot be controlled

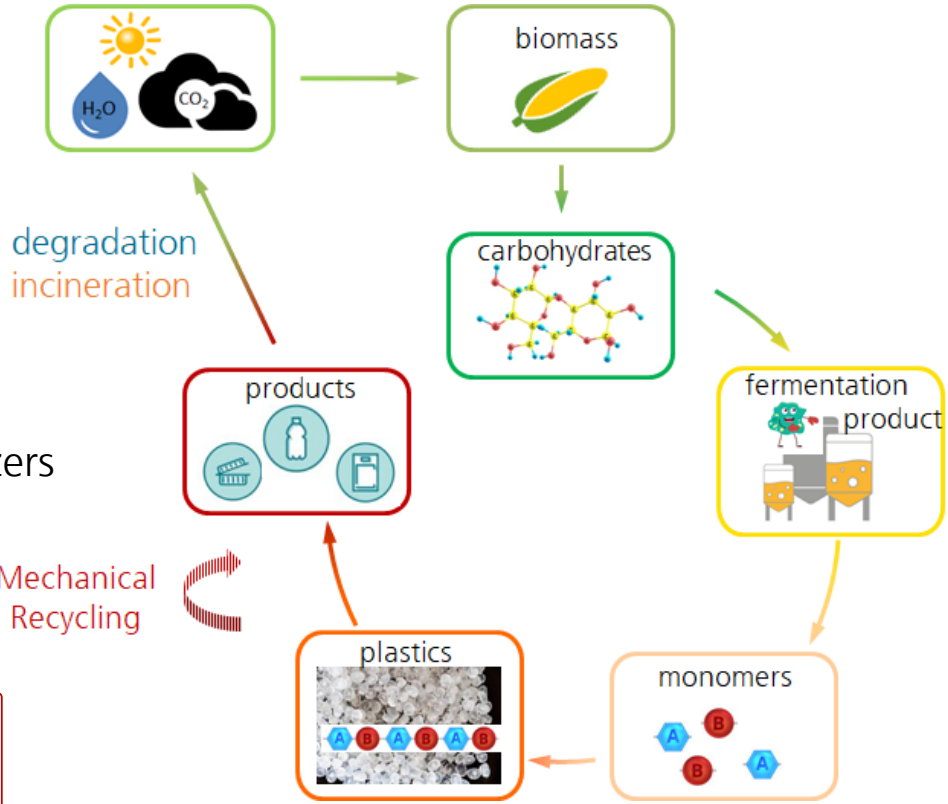
- recovery of part of the energy
- nevertheless high depreciation



# Mechanical Recycling?

- HOWEVER:
  - influences during use and storage
    → MW degradation, discoloration
  - impurities & varietal purity
  - partial compensation through
    AOs / chain / extenders / compatibilizers
  - in general no use in food sector
  - …and in the next cycle???

- if general conditions (drying!) are observed, possible analogously to conventional polymers



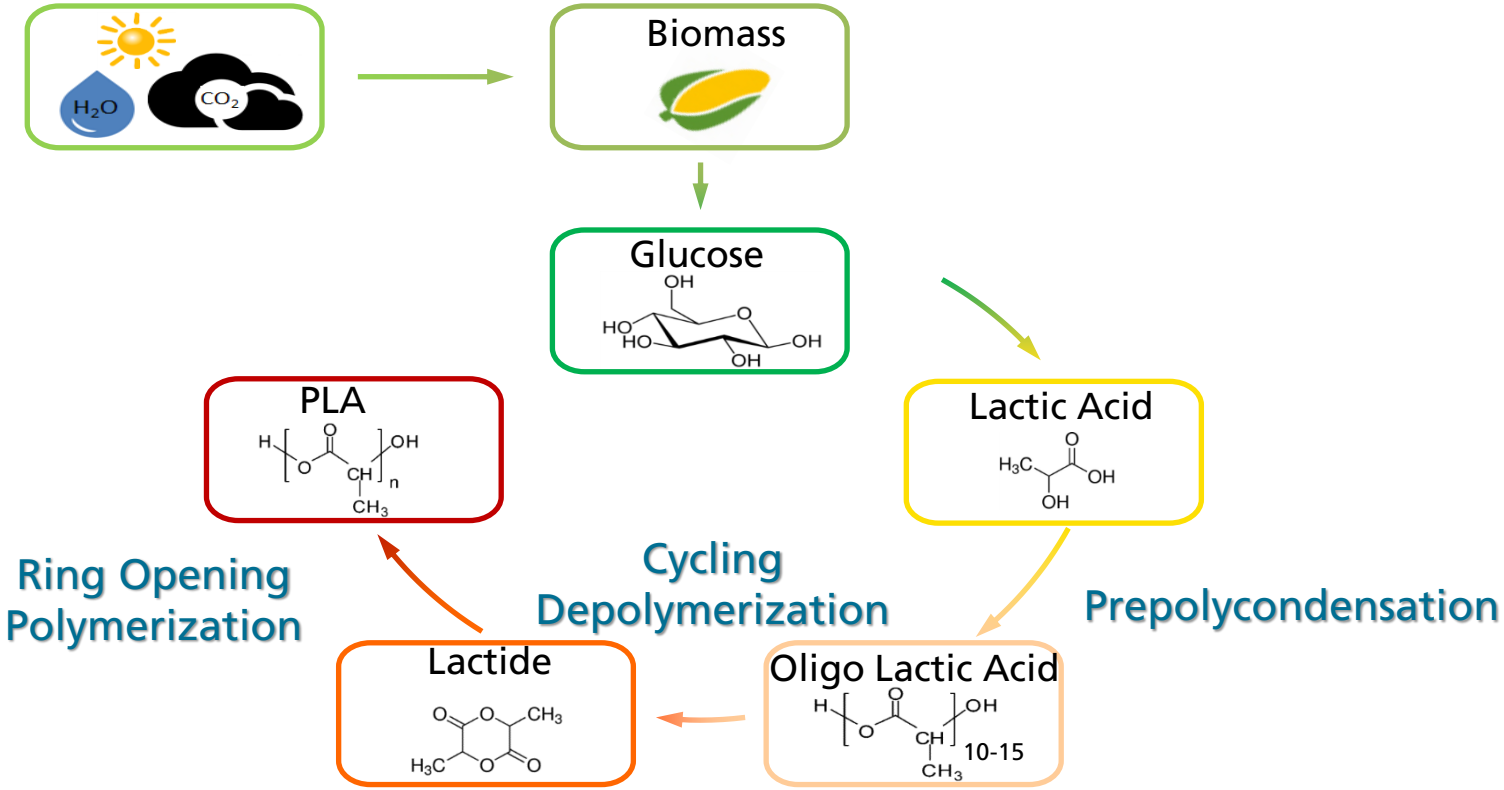



Fraunhofer CCPE

# The PLA case: There's more to it than that!

- PLA with about 10% largest market share after Bio-PET 30 in the biopolymers market
- about 25 producing companies, about 220T t/a production capacity, application adapted qualities
- industrially compostable, partially environmentally degradable, some mechanical recycling options are being investigated
- the underlying chemistry suggests clever chemical recycling

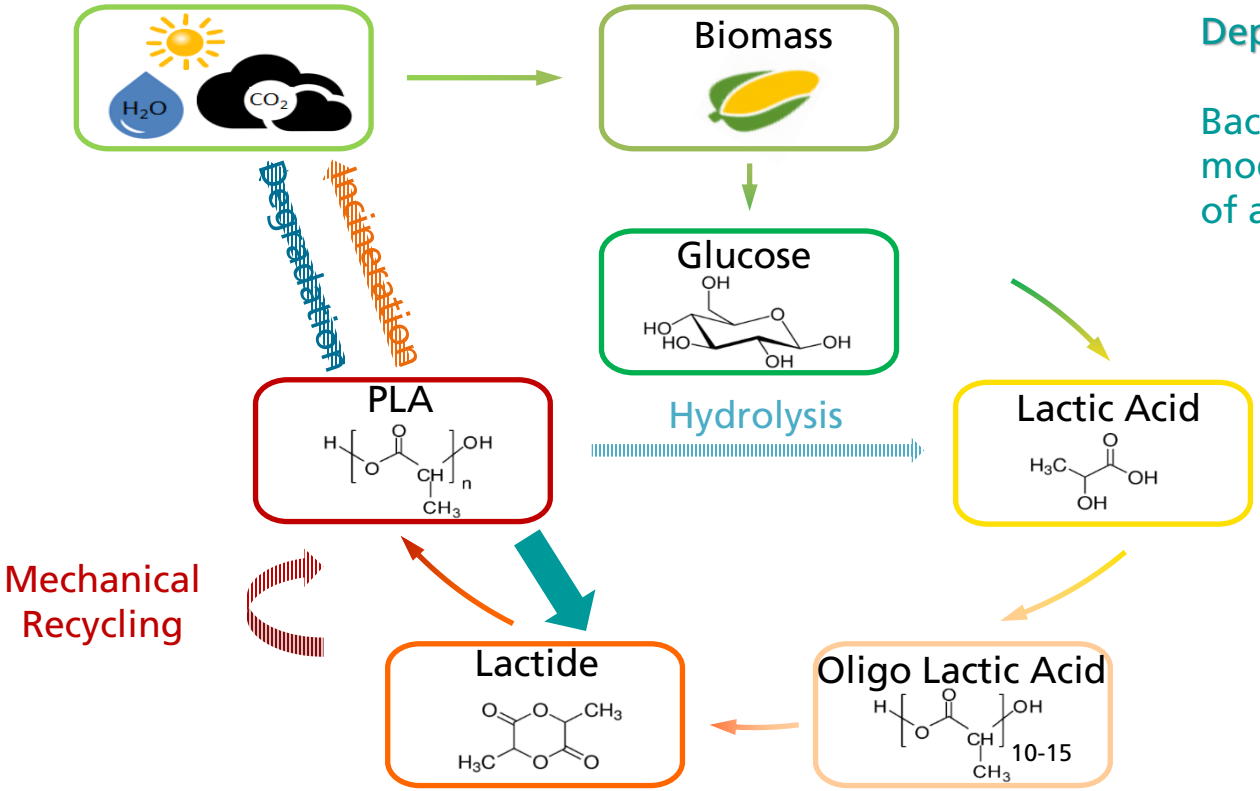
# PLA – Industrial Synthesis Process






Fraunhofer CCPE

# End-of-Life Options for PLA

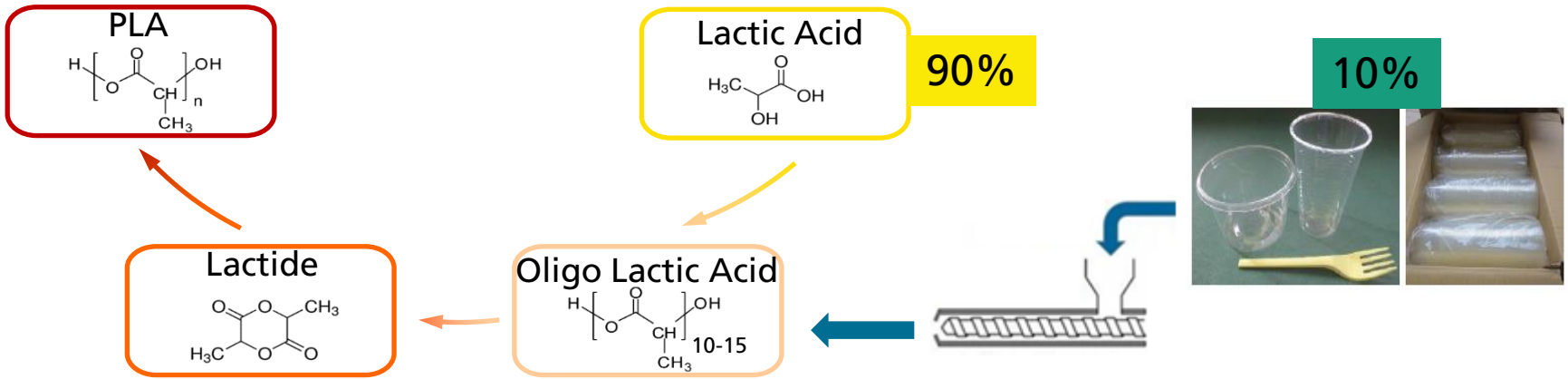



Depolymerization

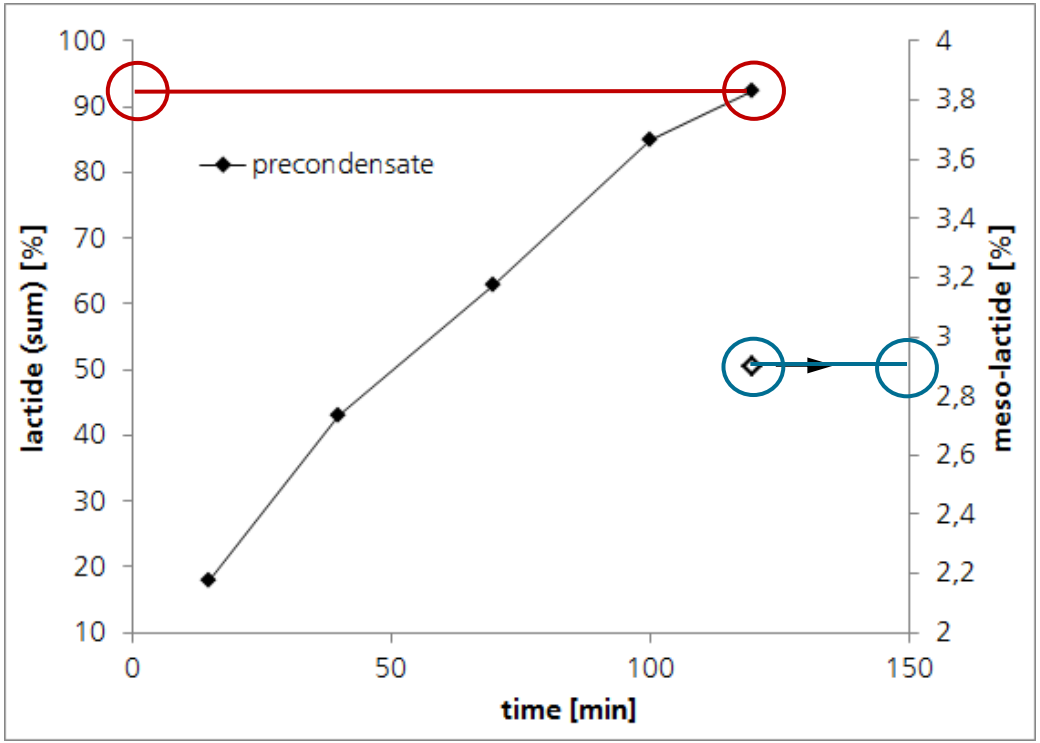
Back to lactide at moderate temperatures of about 200°C

# Concept

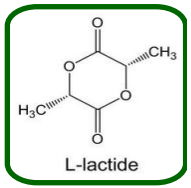
- direct feed of used PLA to the depolymerization reactor of the PLA process
  - using typical process parameters for the investigations
  - aim: direct implementation of recycling into running PLA plants



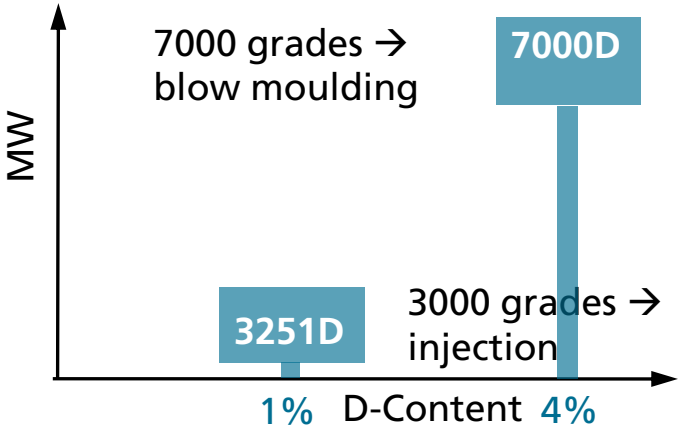
# Baseline for „Non-Disturbed“ Depolymerization Process



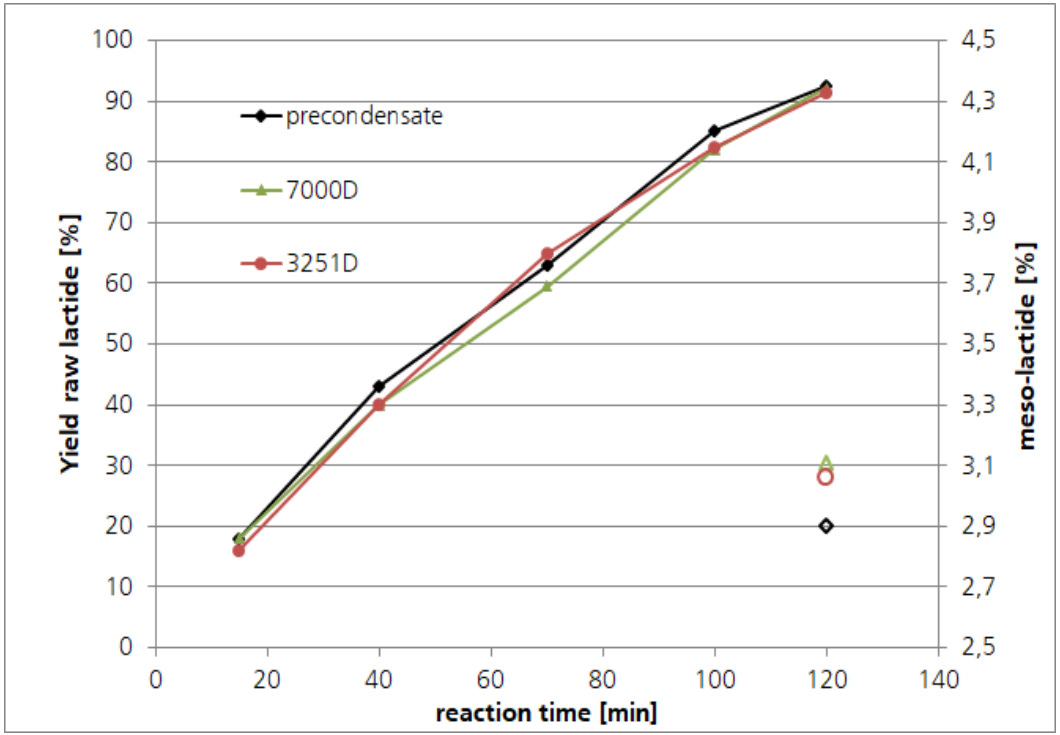

- amount of raw lactide formed during fixed times → rate
- content of meso-lactide → quality




# Recycling of Commercial Ingeo® - Post-Industrial Case




- no influence on reaction rate
- no influence on meso content

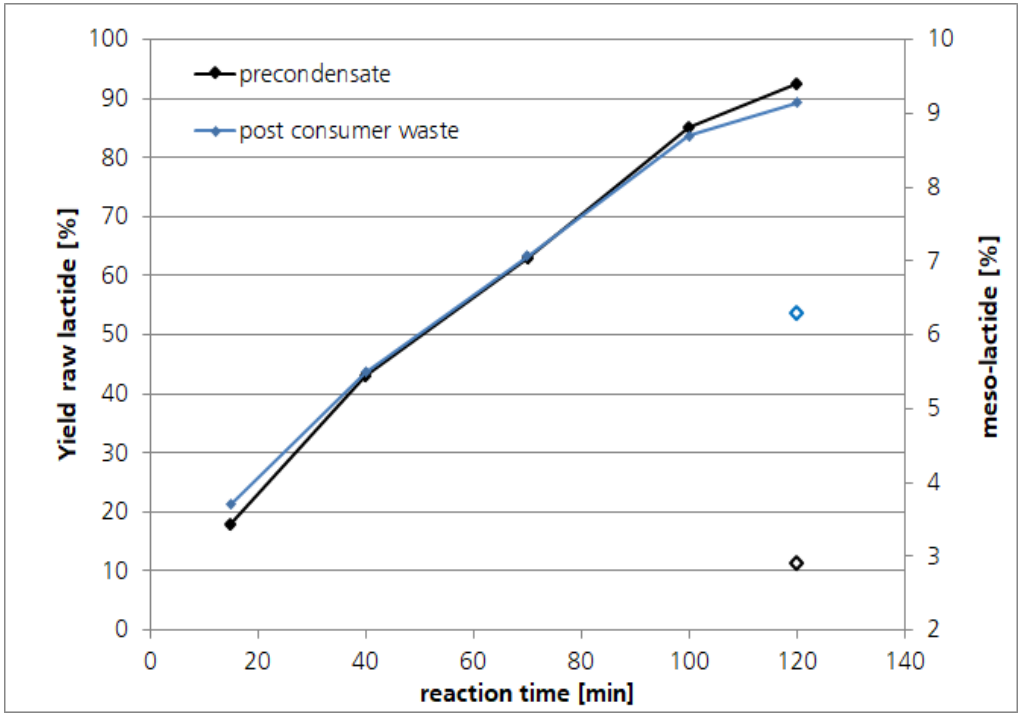





Fraunhofer CCPE

# Recycling of Artificial Post-Consumer Waste (APCW)

- creation of APCW by Knoten Weimar GmbH
- PLA 960kg: yoghurt cups, disposable tableware // LWP waste 11.200kg
- NIR separation , shredded, washed, swim-sink separation, wind sifting
- PLA amount 86%



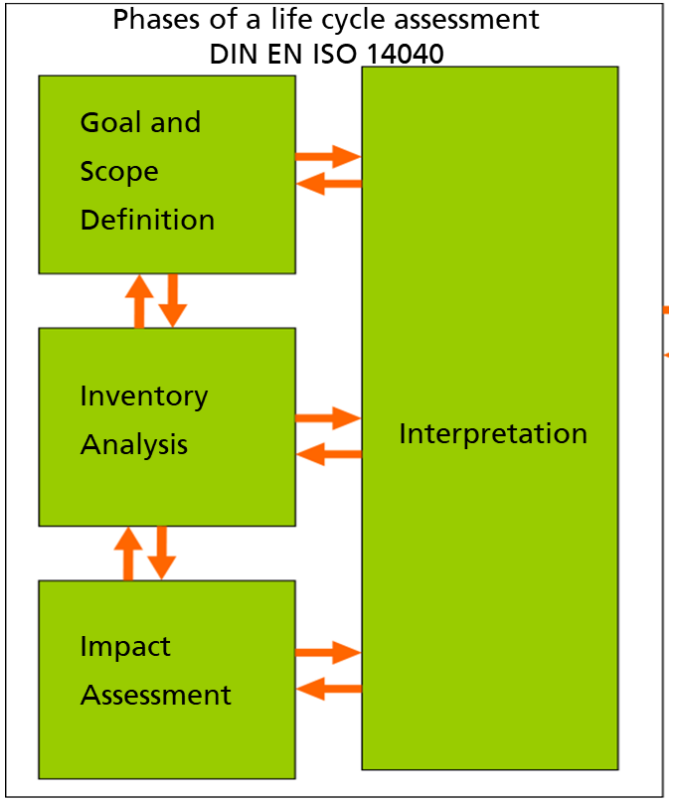

- no influence on reaction rate
- more meso-lactide formed → especially useful in production of „high“D-grades



Fraunhofer CCPE

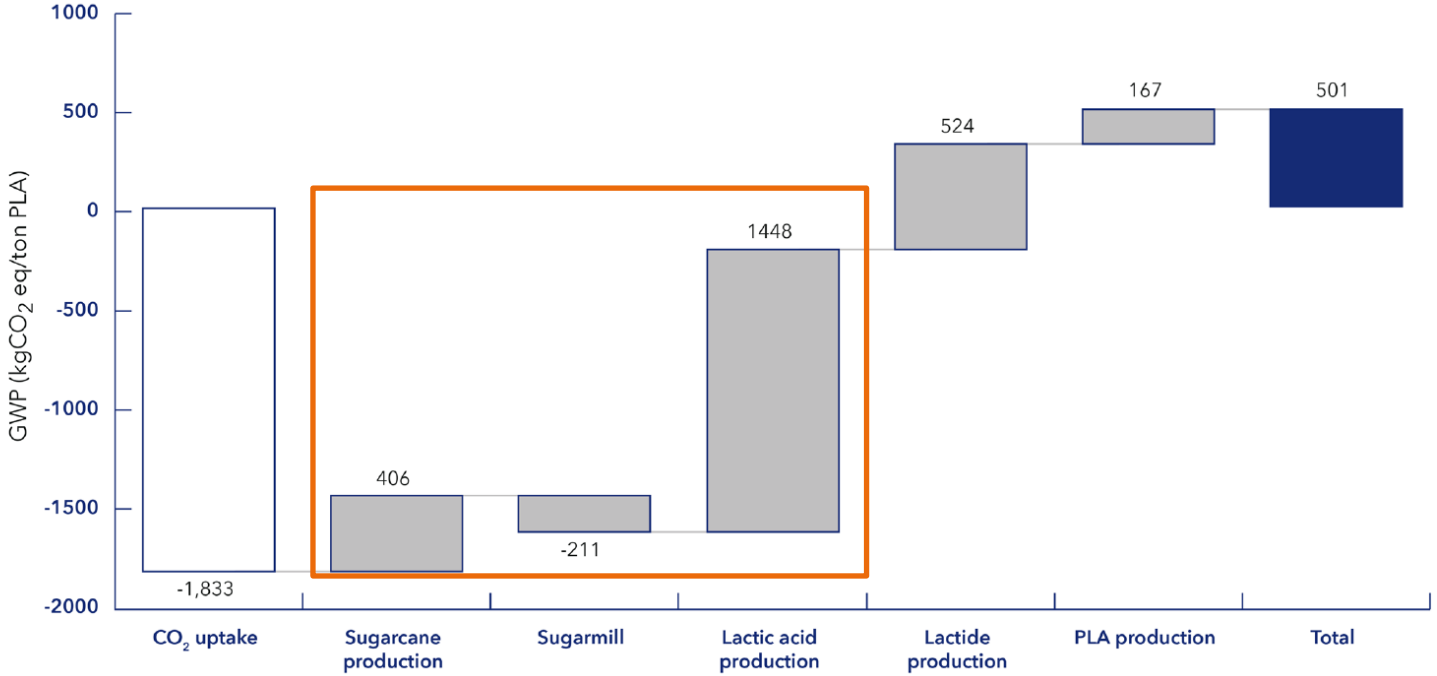
# Life Cycle Analysis of PLA Recycling

- The aim of the LCA is to compare the potential environmental impacts of various end-of-life options for PLA
- Specific questions:
  - Does mechanical and chemical recycling of PLA make sense from an ecological point of view?
  - What are the advantages and possible disadvantages, e.g. compared to the current disposal route via energy recovery?
  - Where are the needs for further optimization and research?



# Results of an LCA for PLA production

## → Chemical recycling of PLA most probably saves lots of GHG emissions




A. Morao, F. de Bie: Journal of Polymers and the Environment, https://doi.org/10.1007/s10924-019-01525-9



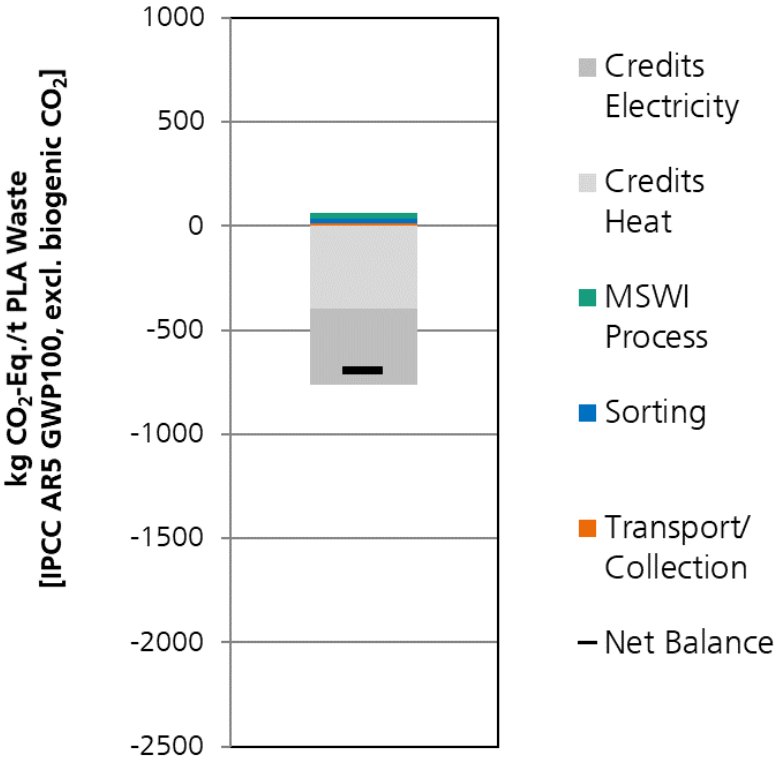
Fraunhofer CCPE

# System boundaries and functional unit

- FU: »Treatment of one ton of PLA waste«
  - Post consumer PLA waste
- 900 kg of virgin PLA can be obtained by chemical recycling
- Comparison to alternative disposal via municipal solid waste incineration (MSWI)

# Reference path: MSWI

- Reference for comparison: municipal solid waste incineration (MSWI) in Germany
  - Emissions: 63 kg $CO_2$-eq./t PLA waste
  - Emissions caused by transport, sorting, and incineration (biogenic carbon excluded)
- Credits: 760 kg $CO_2$-eq. due to substitution of heat and electricity generation
- Balance:
  - Application of MSWI saves approx. 700 kg $CO_2$-eq. emissions per ton waste PLA

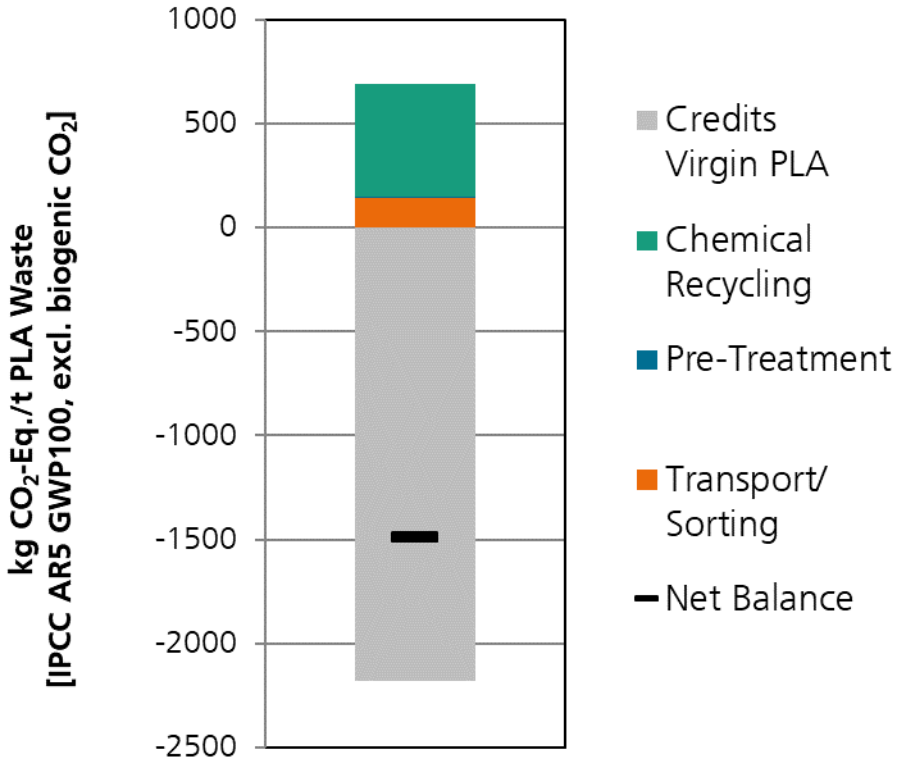





Fraunhofer CCPE

# Chemical Recycling of PLA

- Emissions caused by depolymerisation process and production of new PLA
  - 700 kg $CO_2$-eq./t PLA waste
- Credits: 2 180 kg $CO_2$-eq. due to substitution of 900 kg of virgin PLA
- Balance: application of chemical recycling saves 1 480 kg $CO_2$-eq. emissions per ton of waste PLA

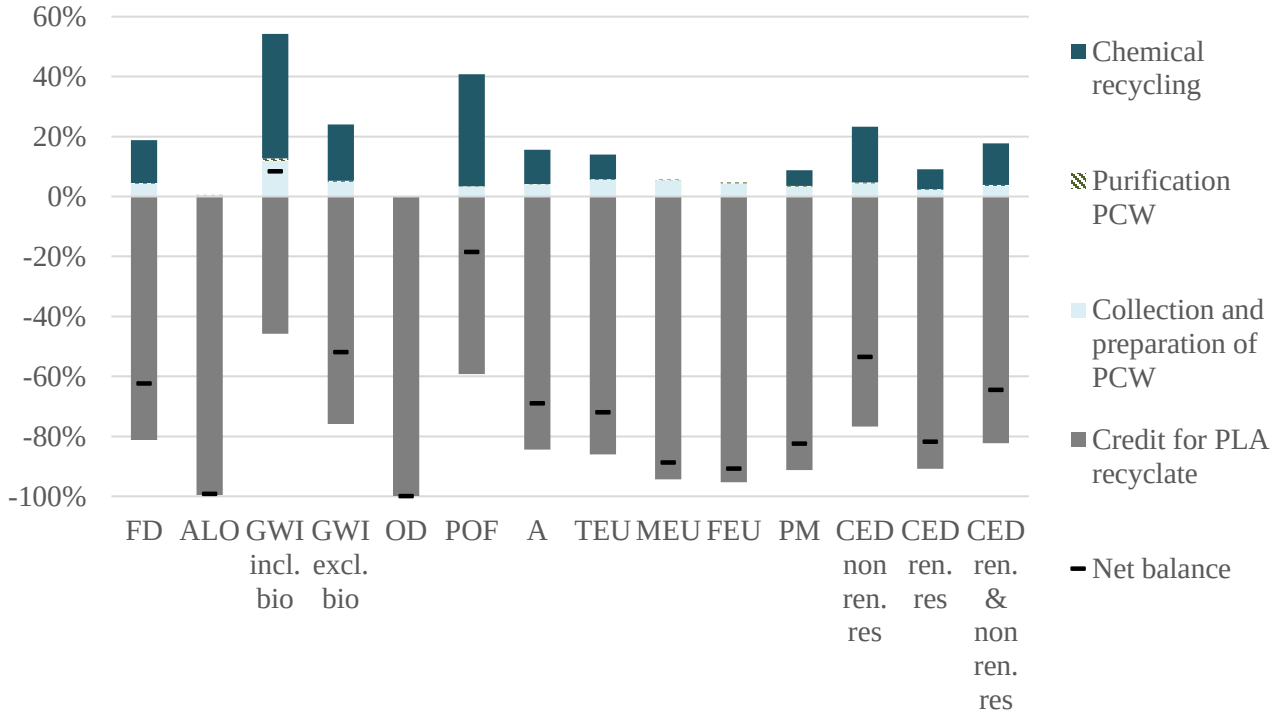





Fraunhofer CCPE

# Chemical Recycling of PLA

- Savings are achieved in all investigated impact categories
- High savings in ozone depletion, land use, eutrophication, acidification

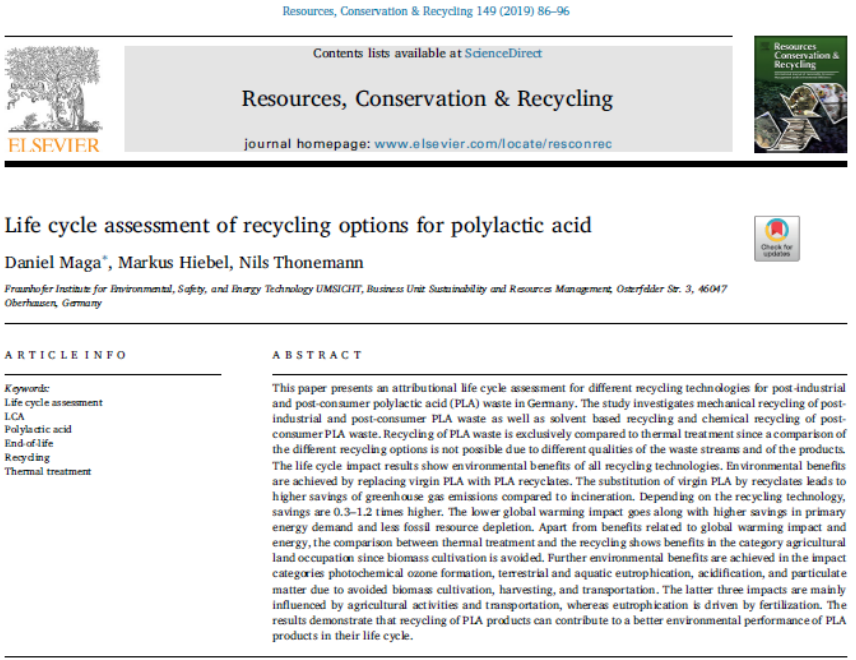



fossil resource depletion (FD), agricultural land occupation (ALO), climate change (GWI), ozone depletion (OD), photochemical ozone formation (POF), acidification (A), freshwater, marine and terrestrial eutrophication (FEU, MEU, TEU), particulate matter (PM), cumulated energy demand (CED)

Fraunhofer CCPE

# Paper on Life Cycle Assessment of recycling options for polylactic acid

- Paper investigates
  - mechanical recycling
  - solvent based recycling
  - chemical recycling
  - of PLA waste compared to incineration
- Results show environmental benefits of all recycling technologies compared to incineration
  - Benefits in global warming and energy demand
  - High benefits by avoiding virgin PLA: agricultural land occupation, photochemical ozone formation, terrestrial and aquatic eutrophication, acidification, and particulate matter



Resources, Conservation & Recycling 149 (2019) 86–96

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

## Life cycle assessment of recycling options for polylactic acid

Daniel Maga*, Markus Hiebel, Nils Thonemann

*Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT, Business Unit Sustainability and Resources Management, Osterfelder Str. 3, 46047 Oberhausen, Germany*

ARTICLE INFO

*Keywords:*
Life cycle assessment
LCA
Polylactic acid
End-of-life
Recycling
Thermal treatment

ABSTRACT

This paper presents an attributional life cycle assessment for different recycling technologies for post-industrial and post-consumer polylactic acid (PLA) waste in Germany. The study investigates mechanical recycling of post-industrial and post-consumer PLA waste as well as solvent based recycling and chemical recycling of post-consumer PLA waste. Recycling of PLA waste is exclusively compared to thermal treatment since a comparison of the different recycling options is not possible due to different qualities of the waste streams and of the products. The life cycle impact results show environmental benefits of all recycling technologies. Environmental benefits are achieved by replacing virgin PLA with PLA recyclates. The substitution of virgin PLA by recyclates leads to higher savings of greenhouse gas emissions compared to incineration. Depending on the recycling technology, savings are 0.3–1.2 times higher. The lower global warming impact goes along with higher savings in primary energy demand and less fossil resource depletion. Apart from benefits related to global warming impact and energy, the comparison between thermal treatment and the recycling shows benefits in the category agricultural land occupation since biomass cultivation is avoided. Further environmental benefits are achieved in the impact categories photochemical ozone formation, terrestrial and aquatic eutrophication, acidification, and particulate matter due to avoided biomass cultivation, harvesting, and transportation. The latter three impacts are mainly influenced by agricultural activities and transportation, whereas eutrophication is driven by fertilization. The results demonstrate that recycling of PLA products can contribute to a better environmental performance of PLA products in their life cycle.

https://www.sciencedirect.com/science/article/pii/S0921344919302319?via%3Dihub

# Conclusions

- Chemical recycling of PLA to lactide is feasible
  - proof of feasibility in batch processes
  - rate of process step depolymerization remains unaffected
  - slightly lower optical purity of lactide suggests preferred use for production of film or blow-moulding grades
  - verification in continuous process necessary
- LCA data show
  - largest savings in greenhouse gas emission and energy demand compared to other EoL , especially
  - also good results for other environmental impact categories when compared to incineration


https://www.umsicht.fraunhofer.de/content/dam/umsicht/en/documents/publications/2017/pla-in-the-waste-stream.pdf

The research project, which was the basis for the results presented, was funded by the German Federal Ministry of Food and Agriculture (BMEL) under grant numbers 22010814, 22031812, 22019212, 22031312, and 22012414.“

Gefördert durch:

Bundesministerium für Ernährung und Landwirtschaft

aufgrund eines Beschlusses des Deutschen Bundestages

FNR
Fachagentur Nachwachsende Rohstoffe e.V.

# THANK YOU VERY MUCH FOR ATTENTION
# LET'S START PLA RECYCLING!

More information available: www.ccpe.fraunhofer.de

**Dr. Antje Lieske**
Fraunhofer IAP
Circular Polymers CCPE®
✆ +49 (0) 331 568-1329
✉ antje.lieske@iap.fraunhofer.de

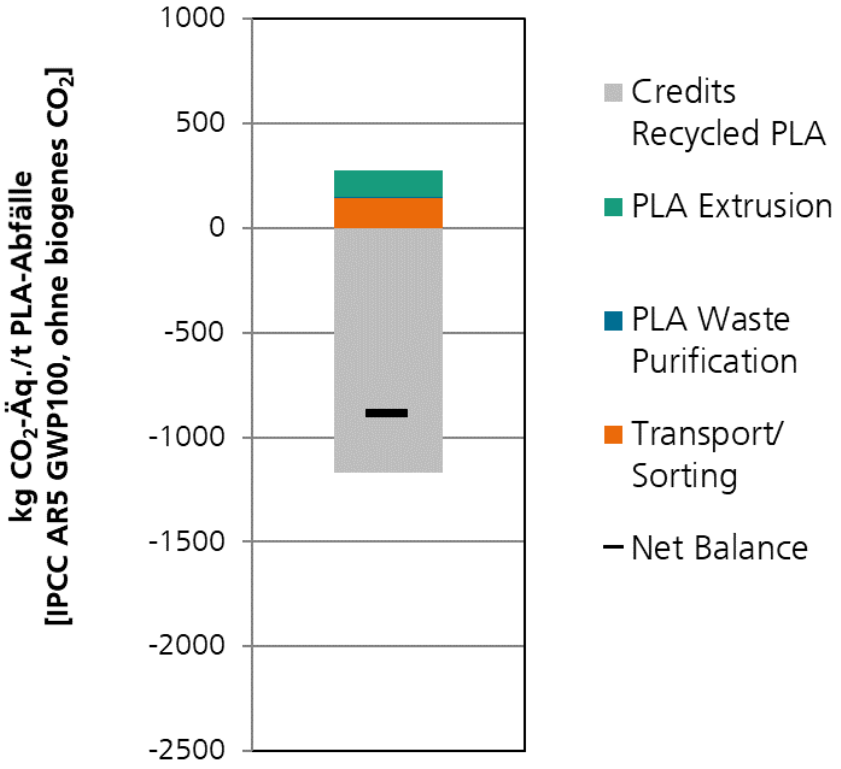
**Dr. Daniel Maga**
Fraunhofer UMSICHT
Circular Logistics and Sustainability CCPE®
✆ +49 (0) 208 8598-1191
✉ daniel.magal@umsicht.fraunhofer.de




Fraunhofer CCPE

# Mechanical Recycling of Post-Consumer PLA Waste

- Emissions: 277 kg $CO_2$-Eq ./t PLA waste
- Emissions caused by transport, sorting, and extrusion with melt filtration
- Credits: 1 170 kg $CO_2$-eq. due to substitution of 498 kg virgin PLA *(50%  because of lower quality)*
- Balance: application of Mechanical Recycling saves approx. 900 kg $CO_2$-Eq. emissions per ton waste PLA






Fraunhofer CCPE